Semi-annual Report, July 15, 1994
Quarterly Report for January - June, 1994
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a) **Objectives**:

The algorithm-development activities at USF continue. We continue to refine our version 1 ATBDs(Algorithm Theoretical Basis Document) as a result of peer review and will submit them to major journals for publishing. We have worked on our initial MODIS algorithm software and will make the delivery to SDST on October 1994. We will also participate on cruises planned for data collection.

b) **Task Accomplished**:

1. An R/V SUNCOASTER cruise was made from Tampa Bay to the Cape San Blas area along the Florida west coast between March 13 and 21, 1994. Tasks included partitioning of the absorption coefficient of water samples, taking CTD and chlorophyll fluorescence profiles, and collecting remote sensing reflectance data for this cruise. Pigment and in-water optical measurements were also made.

2. A remote-sensing reflectance model by Lee et al. (1994) has been accepted for publication by Applied Optics. An additional 9 papers have been presented at National meetings or submitted for publication.

3. Three version 1 ATBDs were completed and submitted to the EOS Project Science Office for panel review:

3-1. Case 2 chlorophyll *a* Algorithm and Case 2 absorption coefficient Algorithm.

Based on a semi-analytical model of remote-sensing reflectance (R_{rs}), Lee et al. (1994), a preliminary algorithm for chlorophyll *a* and gelbstoff parameterized for the Gulf of Mexico has been developed and tested. The Case 2 chlorophyll *a* algorithm and the Case 2 absorption coefficient algorithms (Version 1) use water-leaving radiance (L_W, Product Number 20) measurements from MODIS and downwelling irradiance at the sea surface ($E_d(0^+)$, Parameter Number 4001) to determine remote-sensing reflectance ($R_{rs} = L_w/E_d$), which is then used in a reflectance model to determine chlorophyll *a* concentration ([Chl *a*], Product Number 22, version 1) and the total absorption coefficient (a(_), Product Number 36, version 1) at MODIS wavelengths. The absorption coefficient for colored dissolved organic matter (CDOM, also gelbstoff) at 400 nm ($a_g(400)$) is determined as an interim product. The absorption coefficient is easily determined once [Chl a] and $a_g(400)$ are known. The Case 2 algorithm is based on a bio-optical, semi-analytical model of remote-sensing reflectance (R_{rs}) and is an extension of the irradiance reflectance algorithm for [Chl a] discussed in Carder et al. (1991). The major difference between the earlier algorithm and the present one occurs in the spectral term for the effects of backscattering and the upwelling distribution of radiance. As a result of this change, absorption and backscattering can be separated in the R_{rs} model, and an algorithm that is purely optical can also be derived, i.e., pigment absorption is quantified, as well as pigment concentration.

According to the optical classification by Morel and Prieur (1977), oceanic waters may be characterized as Case 1, in which the optical properties are dominated by chlorophyll and associated and covarying detrital pigments, or as Case 2, in which other substances which do not covary with chlorophyll also affect the optical properties. These substances are primarily CDOM, suspended sediments, detritus, and bacteria. Pigment retrievals from CZCS data in Case 1 waters have achieved reasonable results (± 40% for best cases, Gordon et al., 1983). However, the non-chlorophyll-covarying substances in Case 2 waters have caused the retrieval of pigment concentrations to have inaccuracies as high as 133% (Carder et al., 1991).

Marine CDOM absorbs light in an exponentially decreasing manner as a function of wavelength. Pheopigments, detritus, and bacteria, similarly absorb more strongly at 412 nm than they do at 443 nm. Phytoplankton, on the other hand, absorb more strongly at 443 nm than at 412 nm. These contrasting absorption characteristics are exploited for the purpose of quantifying viable phytoplankton pigments independently from CDOM and other phytoplankton degradation products by MODIS, which will have spectral channels at both of these wavelengths.

The R_{rs} model has numerous parameters that cannot be fixed and applied to the entire globe, i.e., they are site- and season-specific. For example, absorption per unit chlorophyll by phytoplankton can change with species, and with nutrient and lighting conditions by as much as a factor of five (Morel and Bricaud, 1981; Carder et al., 1991; Morel et al., 1993). Also, particle size and concentration both have a significant effect on the spectral backscattering coefficient, b_b(_), of ocean water. This is so because pure water backscatters as _ _$^{-4}$, large particles backscatter as _ _$^{-0}$, and smaller diameter detritus and bacteria backscatter with a spectral dependence somewhere in between the two (Morel and Ahn, 1990; 1991). If many of these factors did not covary, the simple wavelength-ratio algorithms of the CZCS (Gordon and Morel, 1983) would never have worked as well as they did. In trying to understand these covariances, we have developed empirical expressions that depend on chlorophyll or the phytoplankton absorption coefficient at 675 nm for some components of the model.

Extensive field data sets are needed to allow seamless modification of the model parameters with time and space. The changes required will be due mostly to changes in the dominant plankton groups present and the subsequent effects on bio-optical parameters such as pigment packaging. Acquiring such data sets on a global scale should be a major community goal during the next few years. We have developed a scenario that can both guide the parameterization process and provide an initial regional implementation of the algorithm.

The R_{rs} model has numerous parameters that cannot be fixed and applied to the entire globe; i.e., they maybe somewhat site- and season-specific. Extensive field data sets are needed to allow seamless modification of the model parameters with time and space. The changes required will be due mostly to changes in the dominant plankton groups present and the subsequent effects on bio-optical parameters such as pigment packaging. We have collected and tested data from the subtropical as well as high latitude and temperate data from the North Atlantic and Pacific Oceans. A single subtropical parameterization of the algorithm provides pigment accuracies of 30% - 40% for both the Pacific and Atlantic as well as for the Gulf of Mexico data sets tested. A high-latitude parameterization for light-limited, nutrient-replete waters providing twice the pigment packaging worked as accurately for upwelling sites off Washington state and spring bloom sites south of Iceland. Additional cruises to the Indian Ocean and South China Sea are planned for the coming year to evaluate changes to these parameterizations for low latitudes. High-latitude data from 60^{o} N in the Atlantic are being used in the model modification for seasonal effects at higher latitudes.

3-2. Calculating surface PAR(photosynthetically available radiation and IPAR(instantaneous PAR).

Photosynthetically available radiation, PAR, is a measure of the photon flux of quanta available in the wavelength range (350 - 700 nm) where light-harvesting pigments of plants are capable of absorbing and utilizing light. Instantaneous PAR or IPAR is a measure of this variable just below the sea-surface as MODIS passes over. It is required to interpret chlorophyll *a* fluorescence measured by MODIS at 681 nm since IPAR provides the excitation quanta for fluorescence. Since skylight has a different radiance distribution than sunlight, its effective penetration angle below the sea surface differs from that of sunlight. It averages about 32^{o} while sunlight penetrates at angles from 0^{o} to the critical angle (48.5^{o}), depending upon time of the day, latitude, and season. Since skylight differs markedly in color from sunlight, and travels a different slanted path length to depth, and since light attenuation with depth is spectrally dependent, each must be separately designated at the surface in order for models to accurately calculate PAR(z) at depth from their sum. For this reason Surface IPAR should be designated spectrally for each of its sky and solar components. Surface IPAR is designated as Parameter Number 2266 and MODIS Product Number 23. An interim product produced by this algorithm and needed for MODIS Product #22 is the downwelling irradiance, $E_d(\_,0^+)$, just above the sea surface, determined for each of the visible ocean channels of MODIS.

Our surface IPAR algorithm (version 1) calculates irradiance above, $E_d(\_,0^+)$, and just below the ocean surface, $E_d(\_,0^-)$, at high spectral resolution (1 nm) in the range of 350 - 700 nm, and then converts these values for the IPAR estimates. The algorithm requires the following output products from MODIS: aerosol optical depth at 869 nm (product #37), ozone values (product #6), precipitable water (product #4), wind velocity (MODIS Parameter #1688), and the Angstrom exponent (MODIS product #38). Furthermore, the aerosol optical type, E(748,869), interim products for product #37 are also required.

A thorough development of the rationale and theory behind this algorithm is articulated in the following publication:

Gregg, W.W. and K.L. Carder, 1990, A simple solar irradiance model for cloudless maritime atmospheres, *Limnol. Oceanogr.* 35(8): 1657-1675.

The need for PAR(z) at depth for primary production calculations is provided by the following:

Platt, T, and Sathyendranath, S., 1988, Ocean primary production: estimation by remote sensing at local and regional scales, *Science*, 241, 1613-1620.

Platt, T., C. Caverhill and S. Sathyendranath, 1991, Basin-scale estimates of oceanic primary production by remote sensing: the north Atlantic, *J. Geophy. R.*, 96(c8), 15147-15159.

The background for the aerosol models and data needed as inputs to this algorithm are found in the following publication:

Gordon, H.R. and M. Wang, 1994, Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: A preliminary algorithm, accepted for publication in Applied Optics.

In our program we substitute the aerosol model by the MODIS products #37 and #38. They are the atmospheric correction parameters, $E(\_{i},\_{j})$, where i= 1 to 8, and aerosol optical thickness at 869 nm, $t_a(869)$. By using Eq. 35, and 36, the a, $t_a(551)$, and all other $t_a(\_)$ values are calculated.

3-3. Calculating clear-water epsilons.

In the oligotrophic ocean (found typically between 35^{o} N and S), where chlorophyll *a* concentrations are less than 0.25 mg m^{-1}, the remote-sensing reflectance, R_{rs}, and normalized water-leaving radiance, L_{wn}, can be predicted with only a small error for wavelengths longer than about 500 nm (Gordon and Clark, 1981). Under these conditions the aerosol radiance for wavelengths longer than 500 nm can be determined. For large, iron-rich desert dust particles, the ratio of aerosol reflectances at 550 nm and 670 nm, E(550,670), has been found using CZCS data to decrease to 0.9 and below, as opposed to more typical values of 1.0-1.5 for small, non-iron-bearing aerosols. E(550,670) has strong dependence on the iron content of aerosols. Thus, the primary purpose of this algorithm is to use a measured clear-water epsilon value for the MODIS wavelengths 531 nm and 667 nm, E(531,667), over clear waters to estimate aerosol iron content. In addition, for regions where E(531,667) < 1.0, chances are the standard MODIS L_W(_) values at shorter wavelengths will be suspect due to the blue-absorbing aerosols. A second purpose of this algorithm is to recalculate such suspect L_W(_) values over oligotrophic waters using the clear-water epsilon technique and evaluate the chlorophyll error. Lastly, since these effects probably won't be discernable from Angstrom exponents derived using ratios of longer wavelengths (e.g. 670, 750, 870nm), E(531,667) can also provide a check on the Angstrom exponent derived using only red and infra-red wavelengths.

The method for obtaining clear-water epsilon values have been thoroughly documented in the CZCS literature, and no significant alterations to this earlier approach have been applied. We did modify the values of the normalized water-leaving radiance at 520, 550, and 670 nm for CZCS to the slightly different MODIS bands by means of the water absorption curve (note that for low-chlorophyll waters, water is the dominate absorber).

The output product in its simplest form will be E(531,667) maps that scientists can use to evaluate the iron content of aerosols over clear waters (mostly ±35^{o} latitude) and to flag potential problems with L_W values calculated using Angstrom-exponent-based extrapolations from the infra-red for aerosol radiance values in the visible. These would typically be used with L_a(667) to estimate total iron content/flux of aerosol clouds. While 4 km, spatially binned E(531,667) data would be sufficient for most science interests regarding iron flux, diagnosing potential problems with the L_W field may require full-resolution data.

c) **References cited**:

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Carder, K. L., R. G. Steward, J. H. Paul, and G. A. Vargo, Relationships between chlorophyll and ocean color constituents as they affect remote-sensing reflectance models, *Limnol. Oceanogr.*, 31, 403-413, 1986.

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Prieur, L., and S. Sathyendranath, An optical classification of coastal and oceanic waters based on the specific spectral absorption curves of phytoplankton pigments, dissolved organic matter, and other particulate materials, *Limnol. Oceanogr.*, 26, 671-689, 1981.

d) **Published and submitted manuscripts and paper presentations**:

In AGU, 1994 Ocean Sciences meeting in San Diego, Calif., Feb. 21-25, 8 presentations were presented by the individuals of our group. The list is provided in the this section.

1. Lee, Z., K. L. Carder, S. K. Hawes, R. Steward, T. Peacock and C. O. Davis, A model for Interpretation of Hyperspectral Remote-sensing Reflectance, accepted by *Appl. Opt.*

2. Carder, L. K., P. Reinersman, and R.F. Chen, AVIRIS Calibration Using the Cloud-Shadow Method, *Proceeding of the 4th JPL AVIRIS Workshop*, Oct., 1993.

3. Hou, W., D.K. Costello, K.L. Carder, and R. G. Steward, High Resolution Data from the Marine Aggregated Particles Profiling and Enumerating Rover(MAPPER), a new, In-situ, Optical Instrument, poster, O11A-7, AGU, 1994 Ocean Sciences Meeting, *EOS Trans., AGU*, 75(3):21, Jan., 1994.

4. Peacock T.G., K.L. Carder, P.G. Coble, Z.P. Lee, and S.K. Hawes, Long-Path Spectrometer for Measuring Gelbstoff Absorption in Clear Water, poster, O11A-14, AGU, 1994 Ocean Sciences Meeting, *EOS Trans., AGU*, 75(3):22, Jan., 1994.

5. Costello, D.K., K.L. Carder, and R.G. Steward, The Distribution and Optical

Properties of Large Marine Particles: Data From Culture Tank and Field Experiments, O11J-04, AGU, 1994 Ocean Sciences Meeting, *EOS Trans., AGU*, 75(3):35, Jan., 1994.

6. Steward, R.G., K.L. Carder, and T.G. Peacock, High Resolution, in Water Optical Spectrometry Using the Submersible Upwelling and Downwelling Spectrometer (SUDS), O22O-03, AGU, 1994 Ocean Sciences Meeting, *EOS Trans., AGU*, 75(3):102, Jan., 1994.

7. Young, L.R., K.L. Carder, and P. Hallock, Hyperspectral Remotely Sensed Colored Dissolved Organic Matter as a Photoprotective Agent Against Bleaching in Corals and Foraminifera, O22O-10, AGU, 1994 Ocean Sciences Meeting, *EOS Trans., AGU*, 75(3):103, Jan., 1994.

8. Reinersman, P., F. Chen, and K.L. Carder, Monte Carlo Simulation of Atmospheric Point Spread Function With Application to Coastal Image Processing, O22H-08, AGU, 1994 Ocean Sciences Meeting, *EOS Trans., AGU*, 75(3):136, Jan., 1994.

9. Hawes, S.K., K.L. Carder, L.P. Lee, and T.G. Peacock, A Case 1 and Case 2 Bio-optical Algorithm for SeaWiFS, O22H-09, AGU, 1994 Ocean Sciences Meeting, *EOS Trans., AGU*, 75(3):136, Jan., 1994.

10. Lee, Z.P., K.L. Carder, and T.G. Peacock, Hyperspectral Modeling of Remote Sensing Reflectance: From the Florida Shelf to the Mississippi River, poster, O51A-13, AGU, 1994 Ocean Sciences Meeting, *EOS Trans., AGU*, 75(3):193, Jan., 1994.